UCSD PISCES Experiments on Hydrogen Recycling Control with Liquid Lithium (Application to NSTX, CDX-U,…)

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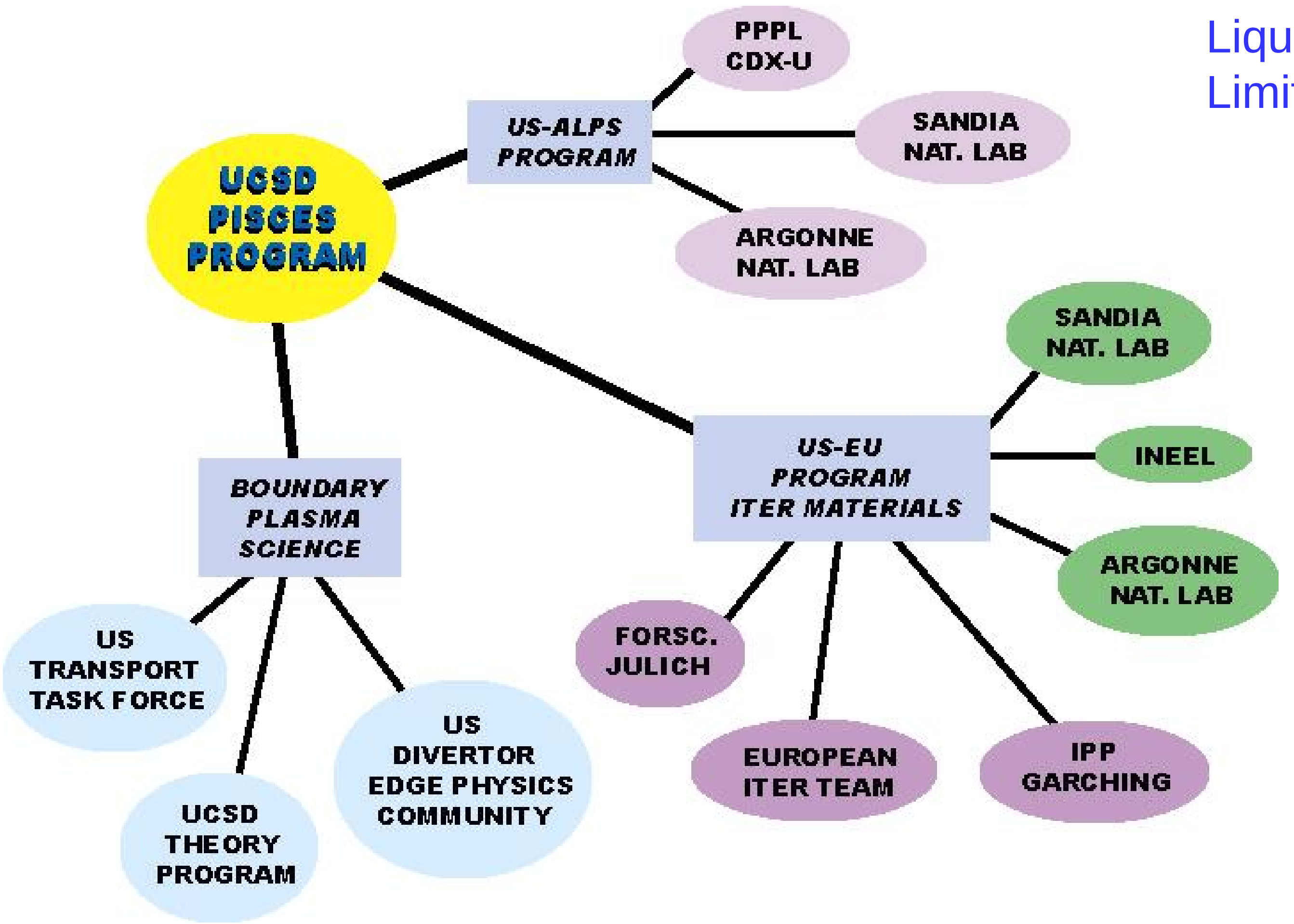
UC San Diego PISCES Program supports project oriented research and basic boundary plasma science research.

Liquid Lithium
Limiter/Divertor



US ALPS Program: Near and long term applications of liquid PFC's

Potential advantages of flowing liquid PFC's

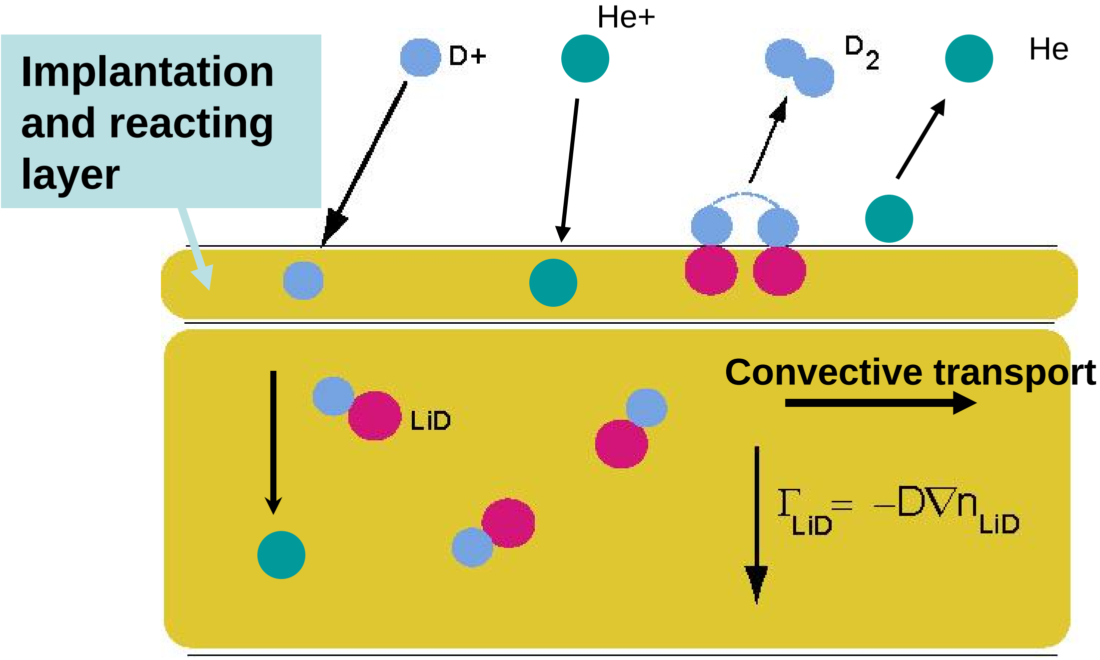
- **Continuously renewable surface: No erosion lifetime limit, Rapid recovery from disruptions/ELMS**
- **Natural Tritium removal/recovery**
- **High heat flux handling, bulk flow heat transport ~50 MW/m^2**
- **Low hydrogen recycling surfaces (CDX-U, NSTX, LTX …)**

R&D issues for liquid PFC's

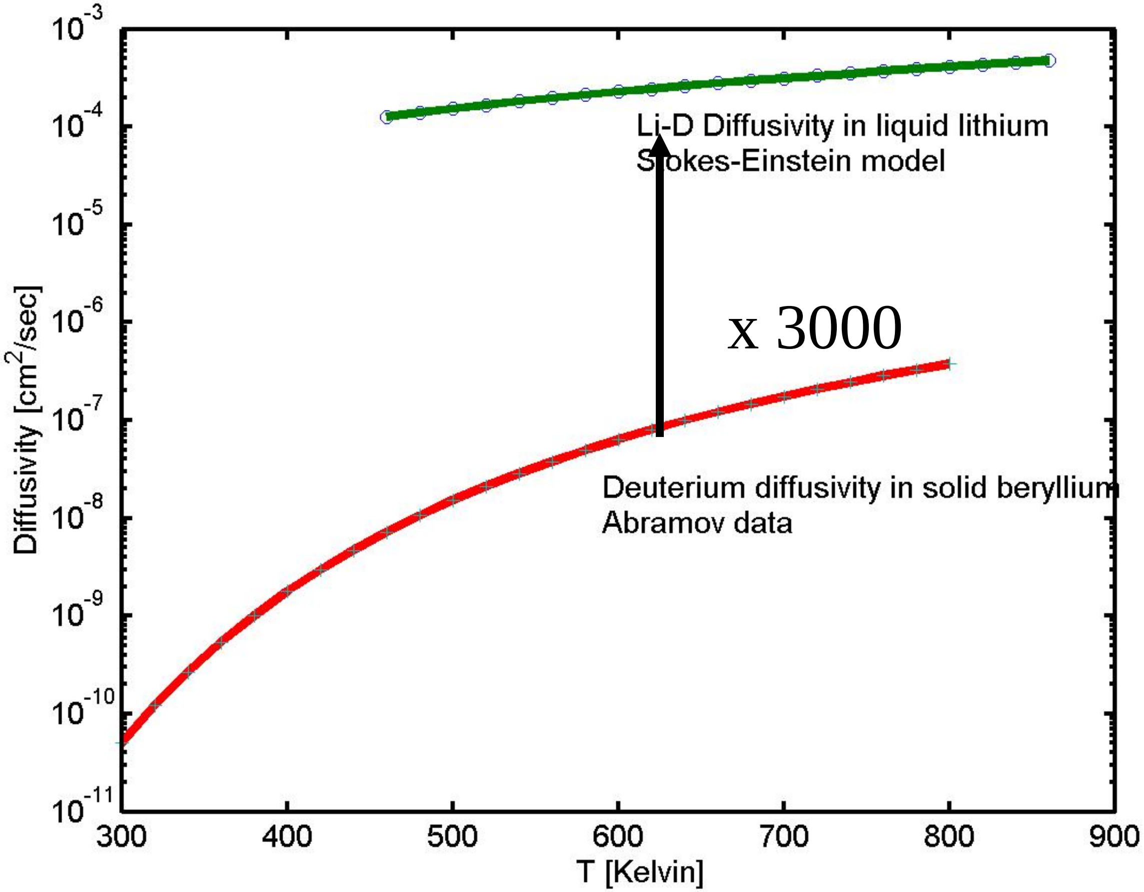
- **Erosion rates and influx rates for Lithium, Gallium, …**
- **Fluid body forces (JxB, dB/dt, pressure pulses)**
  - **Deflection and interruption of flow patterns**
  - **Ejection of droplets, jets, redeposition**
- **Removal rates, transport of H, H_2, He, …**
- **Removal of Hydroxide/oxide layers**

Chemical Retention model for hydrogen isotope retention and release in liquid lithium. Lithium must be in the liquid state!

- Incident hydrogen ions rapidly combine to form LiD in solution.
- Little H2/D2 released from solution (low recombination rate).
- LiD transported into the bulk liquid by diffusion.
- LiD and heat removed from the plasma contact region by convection/diffusion.



LiD (LiH) diffuses rapidly into liquid lithium compared to H/D transport in solid materials. Increased diffusion keeps the lithium surface relatively pure and metallic. Hence low recycling sustained.

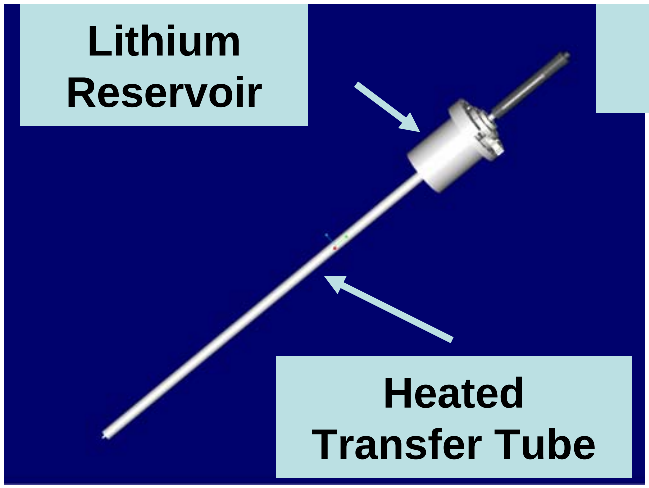


Differences between liquid lithium limiter/divertor and other methods of recycling control.

- Liquid lithium PFCs control recycling by retaining incident <u>hydrogen ion flux</u> (and monatomic H).
- LLPFC's retain hydrogen in an extended <u>relatively thick layer</u> of liquid Li/LiH solution. Little H2 re-released at the surface.
- LLPFCs differ from recycling control by cryo-pumping which pumps neutral hydrogen species, H2/D2 molecules. Plasma ions must recombine to H2/D2 before they can be cryo-pumped.
- LLPFC's differ from wall metallic coatings (gettering) which retain hydrogen in the surface and near surface layers. Passivation limits duration of recycling control.

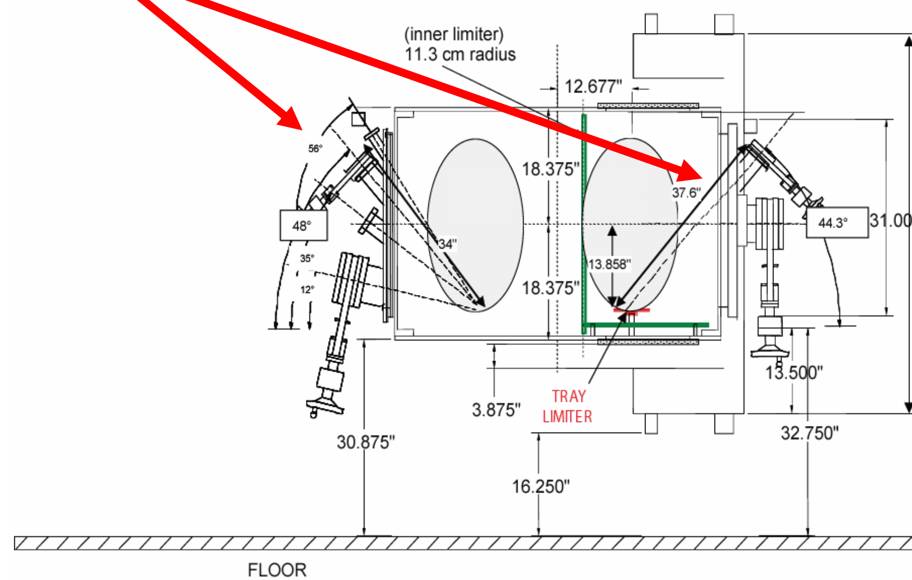
Experimental challenge: Can clean metallic liquid lithium surfaces be made and sustained during tokamak operation?

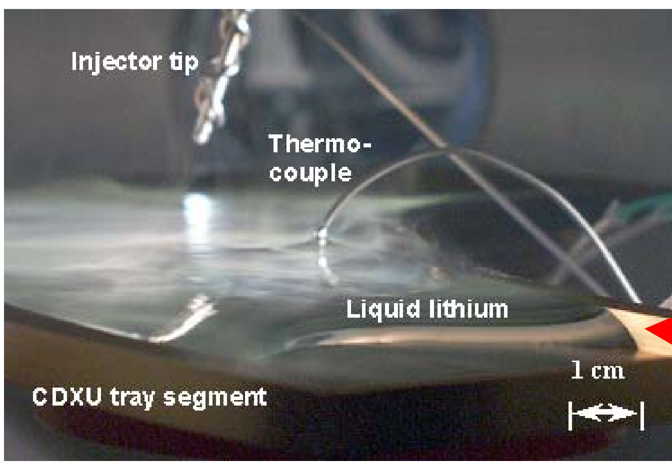
UCSD phase-separator flow delivery system for CDX-U limiter



UCSD Liquid Lithium Phase-separator Injectors

Elevation CDX-U



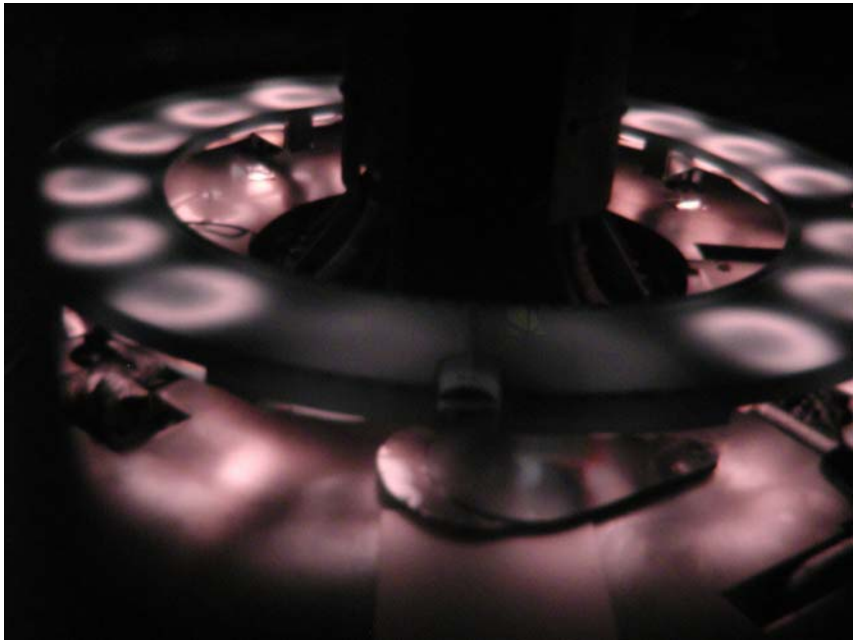


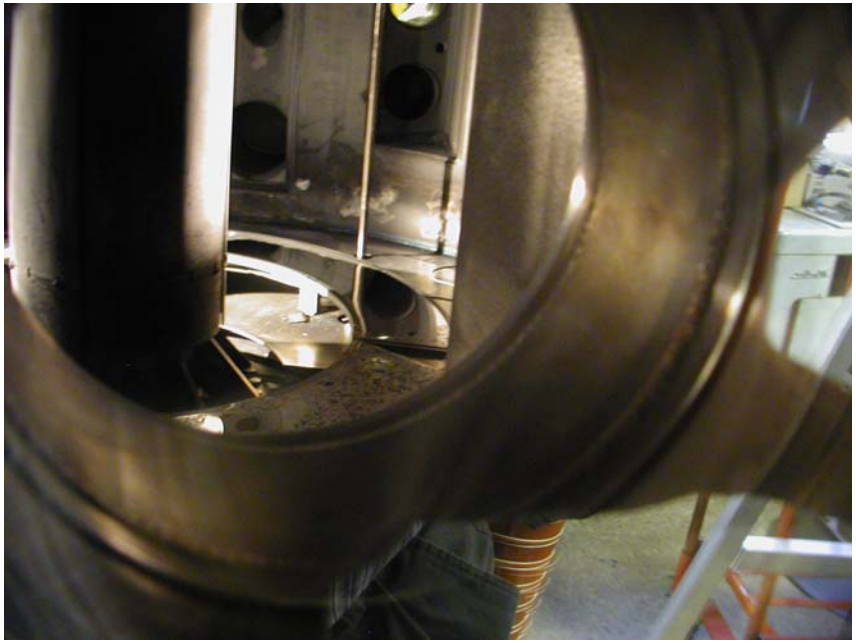
Clean liquid lithium pool formed by phase-separator Injector in test stand at UCSD.

Experiments with toroidal liquid lithium limiter started in CDX-U May 2003

Lithium temperature controlled in CDX-U by heater system.

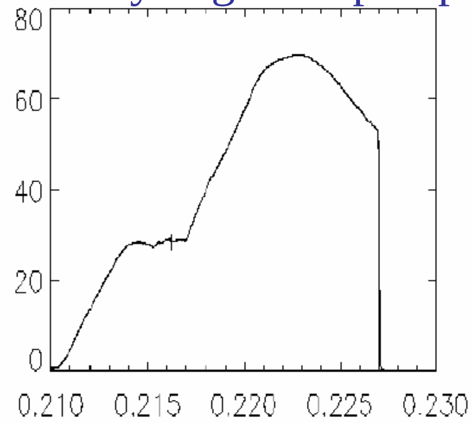
Surface impurity control and overall cleanliness of lithium surface were achieved.

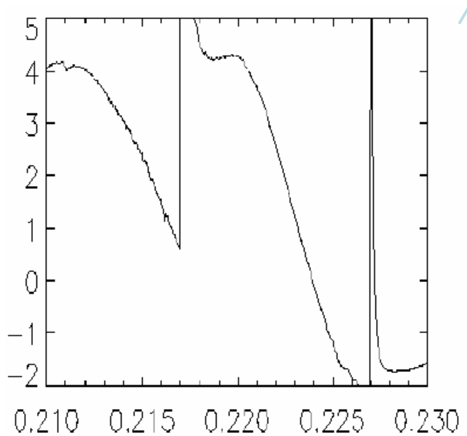


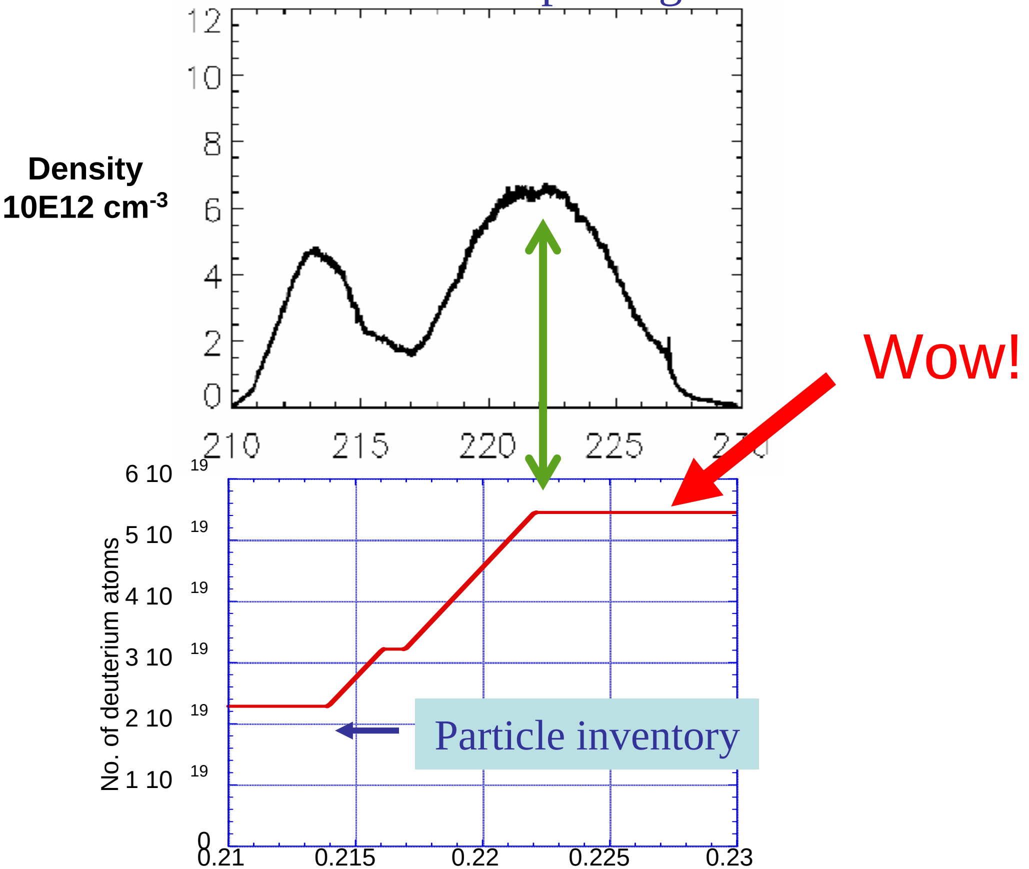


CDX-U plasma discharge with full liquid lithium limiter

- Plasma current requires only ~0.5V for sustainment. Does not terminate until $V_L \Rightarrow$-2V
- Density begins to pump out within ~1msec of cessation of puffing.







FY03-04 Plans Summary
CDX-U Experiment
(As presented at April 03 ALPS Meeting)

- **Liquid lithium tray limiter performance**
- **Surface preparation and maintenance through discharge cleaning (GDC and RF).**
- **Stability of the liquid in tokamak environment, droplet ejection, bulk liquid motion.**
- **Impurity ion reduction**
- **Hydrogen recycling reduction**
- **Influence of limiter on plasma profiles: density profiles, ion and electron temperature profiles, radiation profiles.**

US ALPS Program: Experiments at PISCES, CDX-U, and NSTX

CDX-U

- **Toroidal liquid lithium limiter successfully deployed.**
- **UCSD liquid lithium filling system successful, clean metallic surfaces produced with minimal impurities.**
- **First experiments with plasma showed that lithium was not ejected from tray, that very low recycling of hydrogen was obtained, low impurity levels were verified. Worked as well as we could expect.**
- **2nd series of experiments underway at CDX-U with improved plasma diagnostics. Electrical short in tray heating system, vacuum contamination of lithium, R. Seraydarian from UCSD is on site.**
- **Next step under discussion: replace tray and fix electrical problems, re-do lithium fill, and restart experiments with fresh lithium.**

R&D for NSTX Module A

- **Studies of lithium coatings on graphite: Diffusion of Li into graphite in test stand at UCSD, model temperature response to NSTX divertor heat loads, alternate substrates such as stainless, molybdenum, etc.**

Success of liquid lithium limiter in CDX-U for recycling control motivates further steps at PPPL and US PMI program.

- PPPL NSTX 5 year plan endorses liquid/solid lithium PFC experiments.
- Lithium coating on carbon experiment would connect with TFTR lithium coating experiments.
- Module A: Thick liquid lithium layer on limiter/divertor tiles. Heat flux from plasma used to melt lithium layer.
- Module B: Flowing liquid lithium limiter/divertor. Decision point on flowing liquid lithium divertor module in FY06
- Supporting experiments at CDX-U and PISCES.
- Continue liquid lithium limiter experiments on CDX-U (definitive recycling experiment)

ALPS/CDXU/NSTX Work on Liquid Lithium Limiter/Divertor

Extend liquid lithium technology to NSTX. Prepare for NSTX liquid lithium coating experiment Module A and longer term (FY06) Module B with flow.

FY04 PPPL/UCSD/Sandia Collaboration:

Develop evaporative coating system to apply microns thick coating of liquid lithium onto substrate to be used in tests on NSTX. (MODULE A). CDX-U to be used as a test bed for the NSTX experiment.

- Develop e-beam evaporator for CDX/NSTX (Sandia/UCSD)
- Design and build manipulator arm for evaporator system (PPPL/UCSD)
- Determine compatibility of evaporated lithium coating with various substrate materials (UCSD)
- Model thermal response of lithium coating and substrate for NSTX conditions (Sandia/UCSD)
- Model effects of sweeping divertor leg (UCSD)
- Investigate composition of impurity layers on lithium formed in CDX/NSTX (UCSD)

Boundary Plasma Science Experiments at UCSD PISCES:

New Physics impacts PFC Program from the bottom up.

Plasma Blobs in SOL

- New type of cross-field flux. Detected in PISCES in 2000 (PRL 2001).
- Flux consists of 'blobs' of plasma that move radially away from the plasma and eventually hit the wall material.
- This blob flux has recently been recognized as a potentially important effect for ITER PMI.
- The US PFC/PMI modelers are now focusing on blobs.
- **Importantly, PISCES should do PMI experiments with the blob flux.**

Molecular rotations and vibrations

- Collision cross sections of molecules are strongly dependent on their ro-vib state. Understanding of these processes are recognized as critical for divertor modelers. PISCES experiments are providing important new data. Implications for PMI studies.

Identification of plasma blobs in the Scrape Off Layer of PISCES (2001)

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Experimental Evidence of Intermittent Convection in the Edge of Magnetic Confinement Devices

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(Received 25 January 2001; revised manuscript received 16 April 2001; published 23 July 2001)

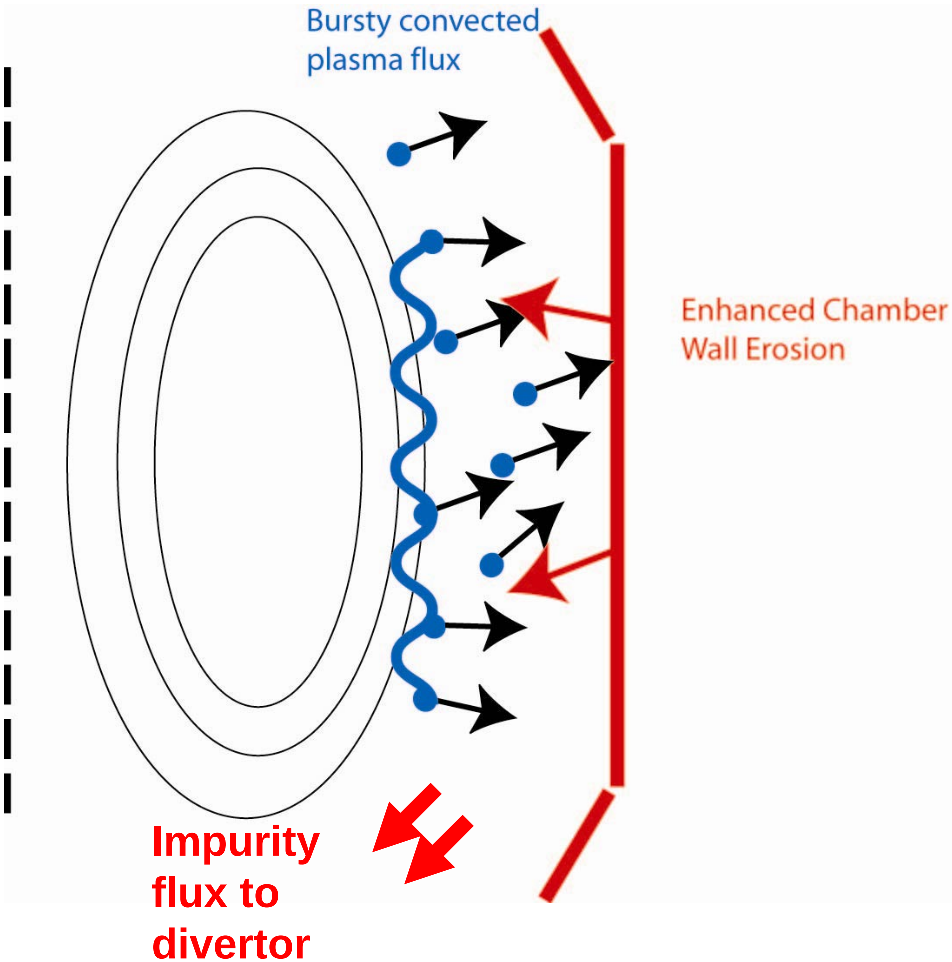
Probe measurements in the PISCES linear device indicate the presence of plasma radially far from where it is produced. We show that this is mainly caused by large-scale structures of plasma with high radial velocity. Data from the Tore Supra tokamak show striking similarities in the shape of these intermittent events as well as the fluctuation density probability distribution and frequency spectrum. The fact that intermittent, large-scale events are so similar in linear devices and tokamaks indicates the universality of convective transport in magnetically confined plasmas.

DOI: 10.1103/PhysRevLett.87.065001 PACS numbers: 52.25.Fi, 52.35.Ra, 52.55.–s

Anomalous transport in fusion plasmas is extensively studied in order to control and enhance the performance of fusion devices. Even after several decades, the nature of such transport is still the subject of intensive research. A purely diffusive model by random drift wave fluctua-

separated by 0.7 mm. The middle tip records the ion saturation current (I_{sat}) and the other two the floating potential (ϕ). In this Letter, the working gas in PISCES is hydrogen. This is also the case for the Tore Supra tokamak which has major and minor radii of 2.32 and 0.76 m and operates

Bursty convected coherent plasma blobs (variously called Avaloids, Blobs, etc.) observed ubiquitously

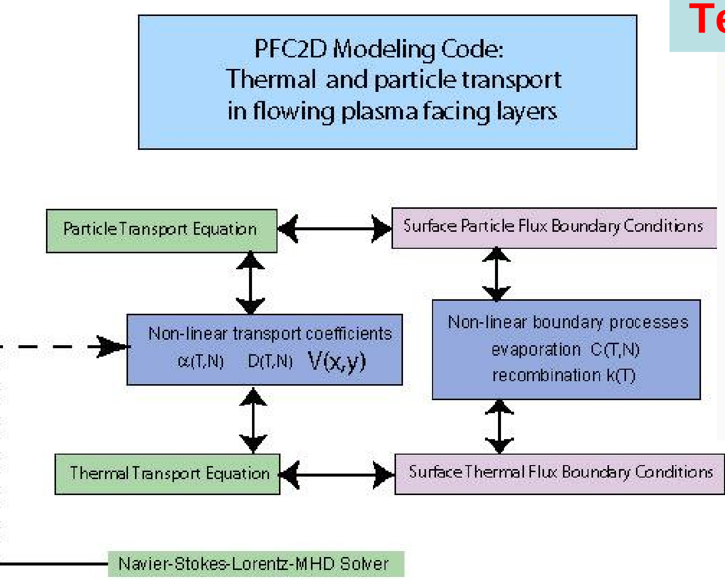


Bursty flux is not well understood and not included in chamber wall flux models.

Bursty flux may generate additional influx of wall atoms

Generating additional impurity flux into divertor

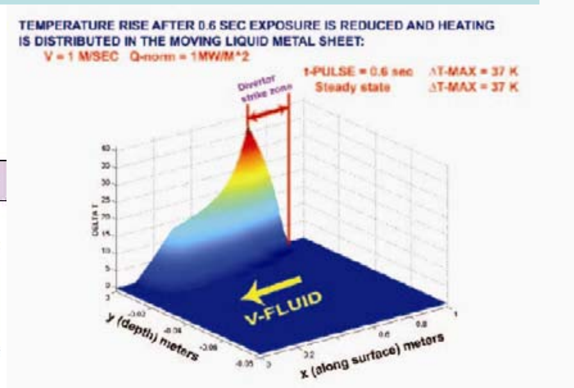
PFC2D modeling code calculates thermal and LiD transport within flowing liquid metals. Solves coupled thermal and particle convective-diffusion equations.



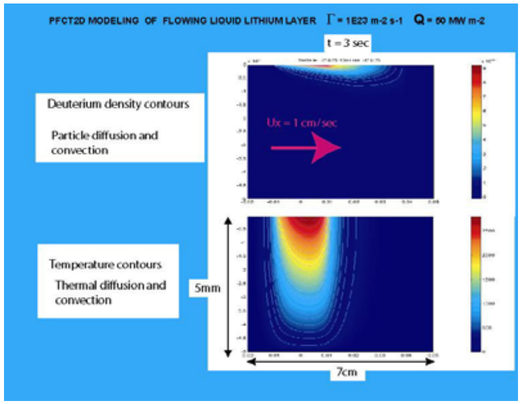
PFC2D capabilities and methods

- Finite element code
- Time dependent or time indepenent modes
- Neumann mixed bondary conditions, non-linear solver

Temperature profiles in 2D



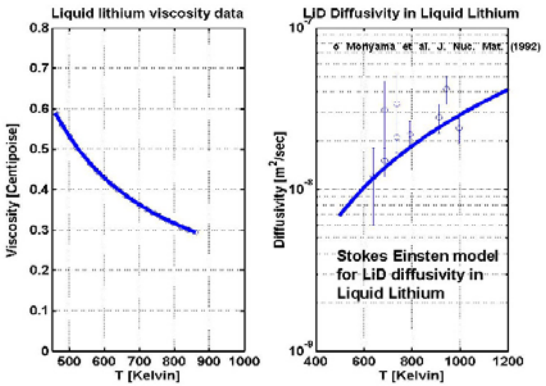
LiD density and Temp. profiles in 2D



Accurate theory for diffusion in liquid metals:

Stokes-Einstein model.

$$D = \frac{kT}{6\pi\ \mu(T)\ R_{mol}}$$



University of California San Diego

PPPL PRINCETON PLASMA PHYSICS LABORATORY

US ALPS PFC MEETING
Chicago 11/03

CDX-U plasma discharge with toroidal liquid lithium limiter

(R. Majeski et al. this meeting)

- Plasma current requires only ~0.5V for sustainment. Does not terminate until $V_L \Rightarrow -2V$
- Density begins to pump out within ~1msec of cessation of puffing.